

KOD175B.001APC

Specification

BULKY PAPER

5

Field of the Invention

This invention relates to a bulky paper that contains specific polyacrylamides.

This invention also relates to a bulky paper that provides improved paper-strength properties such as higher tensile strength and interlayer strength without increasing paper density, while also offering good optical characteristics such as opacity and brightness.

Background of the Invention

Concurrent with the growing awareness of environmental protection among the public and the need to reduce the production costs of paper, pulp consumptions are decreasing and the papers used for making books and newspapers are becoming bulkier.

15 Methods to increase paper bulk include the reduction of press pressure in the press process of paper production, elimination of calendering that is usually carried out to increase the smoothness of paper surface, and application of calendering at a low line pressure. However, these methods often result in lower smoothness and printability. There are other ways to increase paper bulk, such as the use of amorphous silica or silicate having a specific bulk density of 0.3
20 g/ml or less (Japanese Patent Application Laid-open No. 10-226982), utilization of specific alcohol and/or its polyoxyethylene adduct as a bulk-increasing agent—a chemical used to reduce paper density (WO98/03730), use of ester compound of polyhydric alcohol and fatty acid as a bulk-increasing agent (Japanese Patent Application Laid-open No. 2000-34691), method to use bridged pulp (Japanese Patent Application Laid-open No. 4-185792), method to use mercerized
25 pulp (Japanese Patent Application Laid-open No. 7-189168), mixing of synthetic fibers into the material when making paper (Japanese Patent Application Laid-open No. 3-269199), method to fill inorganic material in the gaps between pulp fibers (Japanese Patent Application Laid-open No. 3-124895), and method to utilize foaming particles that generate air gaps (Japanese Patent Application Laid-open No. 5-230798). However, the bulky papers produced by the above
30 methods are likely to pose quality problems, including reduced paper-strength properties such as lower tensile strength and interlayer strength.

Utilization of various paper-strengthening agents is one means for improving paper

strength. Polyacrylamides and starches are two of the representative types of paper-strengthening agents that are widely used today. However, bulky papers made with general paper-strengthening agents can have poor density, opacity or brightness, although their paper strength is higher. In this sense, there is a need to selectively use optimal paper-strengthening agents.

5 In light of the above challenge, the present invention aims to provide a bulky paper offering improved paper strength and good optical characteristics.

Summary of the Invention

10 The inventors of the present invention have carried out extensive studies to solve the problems described above, and as a result have clarified the effects of blending various paper-strengthening agents into bulky papers. First, the inventors have found that use of starch-based paper-strengthening agents, the representative examples of which are cationic starches and amphoteric starches, often results in the obtained paper having higher density and poor optical characteristics, particularly in the form of reduced opacity. According to the
15 measurement of the relative bonding area, which is an indicator of the interfiber bonding area of paper whose increase is suspected as a cause of the above problems, the relative bonding area of a paper containing starches had a significantly higher relative bonding area compared with a paper not containing any starches. In the meantime, comparisons of relative bonding area between bulky papers produced by various methods on one hand, and a normal-density paper on the other,
20 were conducted. For example, in the comparison between a bulky paper produced with bulk-increasing agents and a paper not produced with any bulk-increasing agents, the bulky paper containing bulk-increasing agents had a significantly smaller relative bonding area compared with the paper not containing any bulk increasing agents. In other words, starches and bulk-increasing agents have opposing effects on the relative bonding area, and a combined use of
25 the two is likely to have negative effects on density and opacity.

On the other hand, it has been found that polyacrylamide-based paper-strengthening agents can be classified into two groups: those that increase density and therefore prevent bulk from increasing, and others that improve paper strength without affecting density or bulk and by maintaining good optical characteristics.

30 Polyacrylamides, which are used as paper-strengthening agents, exhibit different levels of paper-strengthening performance, coagulation, retention and drainage depending on: the

molecular shape, such as linear or branched/bridged; the type and quantity of anionic groups, the representative of which are carboxyl groups; the type and quantity of cationic groups, the representative of which are tertiary amine and/or quaternary ammonium cation groups; and the distribution pattern of cationic and/or anionic group molecules, such as random, block or grafted.

5 The researchers have found that the polyacrylamides that improve the paper strength of a bulky paper without affecting its density and also cause the paper to manifest good optical characteristics contain both anionic groups and cationic groups in small quantities. The polyacrylamides containing small quantities of anionic groups and cationic groups have a larger quantity of amide groups that manifest strength through hydrogen bonding to pulp. As a result,
10 these polyacrylamides increase bonding strength, which is assumed to be the reason for their ability to improve paper strength efficiently and enhance optical characteristics without affecting density.

 Unlike starches, polyacrylamides generally have minimal effects on the relative bonding area. The researchers have also found that the polyacrylamides that improve paper strength
15 without affecting density or bulk and by maintaining good optical characteristics are characterized by a specific relative bonding area manifested by a bulky paper containing these polyacrylamides, which is 1.2 times the relative bonding area of a bulky paper not containing these polyacrylamides, or less.

20 Best Mode for Carrying out the Invention

 The present invention is explained in details below.

 The polyacrylamides used in the present invention have in the same molecule both anionic groups, the representative of which are carboxyl groups, and cationic groups, the representative of which are tertiary amine and/or quaternary ammonium cation groups, and whose
25 electric charge is 2.0 m-equivalent/g or less at pH2 and also 2.0 m-equivalent/g or less at pH12. The electric charge at each pH level indicates the differential quantity between cationic groups and anionic groups that are active at that pH level. Polyacrylamides usually exhibit a positive potential at pH2 where cationic groups are more active, and a negative potential at pH12 where anionic groups are more active.

30 The polyacrylamides used in the present invention are produced by copolymerizing at least one of acrylamide monomers, cationic monomers and anionic monomers.

The most preferable type of acrylamide monomers used for producing the polyacrylamides described in the present invention is acrylamide or methacrylamide. Other desirable acrylamide monomers include N-substituted, water-soluble low-grade alkyl acrylamides, such as N-ethyl acrylamide, N,N-dimethyl acrylamide, N-isopropyl acrylamide and diacetone acrylamide, which can be used alone or in any combination.

Examples of cationic monomers include tertiary amine monomers, such as N,N-dimethyl aminoethyl (meth)acrylate, N,N-diethyl aminoethyl (meth)acrylate, N,N-dimethyl aminopropyl (meth)acrylate, N,N-diethyl aminopropyl (meth)acrylate, N,N-dimethyl aminopropyl (meth)acrylamide, N,N-diethyl aminopropyl (meth)acrylamide, arylamine and diarylamine; the hydrochloride, sulfate, acetate or other inorganic salt, or organic salt, of the aforementioned tertiary amine monomers; or quaternary ammonium salt monomers produced by reacting tertiary amine monomers with methyl chloride, benzyl chloride, dimethyl sulfate, epichlorohydrin, etc. These cationic monomers can be used alone or in any combination.

Examples of anionic monomers include monomers containing carboxyl groups, including monocarboxylates such as acrylate, methacrylate and crotonate, or dicarboxylates such as maleate, fumarate, itaconate, citraconate and muconate. These anionic monomers can be used alone or in any combination.

As nonionic monomers, the aforementioned anionic monomers including alkyl ester (where the carbon number of the alkyl group is 1 to 8), acrylonitrile, styrene chain, vinyl acetate and methyl vinyl ether can be used alone or in any combination.

In addition, any one or more of the following bridging monomers can be used: di(meth)acrylates such as ethylene glycol di(meth)acrylate, diethylene glycol di(meth)acrylate and triethylene glycol di(meth)acrylate; bis(meth)acrylamides such as methylene bis(meth)acrylamide, ethylene bis(meth)acrylamide and hexamethylene bis(meth)acrylamide; divinyl esters such as divinyl adipate and vinyl sebacate; bifunctional vinyl monomers such as acryl methacrylate, diaryl amine, diaryl dimethyl ammonium and diaryl phthalate; and trifunctional vinyl monomers such as 1,3,5-triacryloyl hexahydro-S-triazine or triaryl isocyanurate.

The polyacrylamides used in the present invention should preferably have an electric charge of 2.0 m-equivalent/g or less at pH2 and also 2.0 m-equivalent/g or less at pH12, but more preferably the electric charge should be 1.5 m-equivalent/g or less at pH2 and 1.8 m-equivalent/g

or less at pH12. In addition, it is effective to use those polyacrylamides that cause the relative bonding area of a bulky paper in which they are contained to become 1.2 times the relative bonding area of a bulky paper in which they are not contained, or less.

The average molecular weight of the polyacrylamides used in the present invention
5 should be preferably 2 to 4 million, but more preferably 2.5 to 3.5 million.

If the polyacrylamides proposed by the present invention are added to the paper during the paper production process, it is preferable to add 0.01 to 3.0 weight percent, or more preferably 0.05 to 1.5 weight percent, of polyacrylamides relative to the absolute dry weight of pulp.

Bulky papers that contain the polyacrylamides proposed by the present invention include
10 those produced at a lower press pressure in the press process of paper production, those produced without calendering that is usually carried out to increase the smoothness of paper surface, and those produced with calendering performed at a low line pressure.

Other examples of these bulky papers include those produced with the following fillers having a specific bulk density of 0.3 g/ml or less: amorphous silica obtained by reacting sodium
15 silicate with sulfuric acid; silicate obtained by reacting sodium silicate and sulfuric acid in the presence of other inorganic compound, such as hydrated aluminum silicate or hydrated sodium aluminum silicate; and amorphous silicate such as hydrated calcium silicate or hydrated magnesium silicate.

Yet other examples of the aforementioned bulky papers include those produced with
20 so-called bulk-increasing agents—chemicals that are used to reduce paper density—including the following: fatty-acid polyamide polyamine compounds; and ester compounds of polyhydric alcohol and fatty acid such as ethylene oxide adduct of stearyl alcohol, propylene oxide adduct of stearyl alcohol, ethylene oxide adduct of decyl alcohol, and pentaerythritol stearate or monoglyceride stearate.

Examples of the aforementioned bulky papers further include those produced with
25 bridged pulps that are made using the following bridging agents: dimethylol ethylene urea and dimethylol dihydroxyethylene urea containing a functional group reacting with the hydroxyl groups in celluloses; and ethylene glycol diglycidyl ester and dihydroxy ethylene urea. Other examples include bulky papers using mercerized pulps made by processing pulps in an aqueous
30 alkaline solution.

Bulky papers produced by mixing in synthetic fibers, by filling inorganic material in the

gaps between pulp fibers, or by utilizing foaming particles that generate air gaps, are also included in the aforementioned bulky papers.

The bulky paper obtained by the present invention can be used as: an uncoated printing paper such as fine printing paper, wood containing printing paper or newsprint paper; base paper for art paper, cast coated paper or fine coated paper; or recording paper such as PPC paper, inkjet paper, laser printer paper, form paper, thermal transfer paper, thermo-sensitive recording paper or pressure-sensitive recording paper.

[Examples]

The following describes the present invention in details by using specific examples. Note that the present invention is not limited to these examples.

Unless otherwise specified, the percent used in the examples refers weight percent.

<Calculation of the Electric Charge of Polyacrylamide>

The electric charges at pH2 and pH12 were measured for the polyacrylamides shown in Table 1.

The results are shown in Table 1.

○ Electric charge at pH2

Deionized water was added to the polyacrylamide to a concentration of 0.5 g/l, to which an aqueous hydrochloric acid solution was added to adjust the pH level to 2. The mixture was let stand for 5 minutes, and then titrated on a particle surface electric-charge measuring equipment [Model PCD03, manufactured by Mutek] using polyvinyl potassium sulfate (PVSK).

The electric charge at pH2 was obtained using the formula below:

$$\text{Electric charge (m-equivalent/g)} = V \times C / W$$

(V in the formula represents the titer of PVSK (ml), C represents the concentration of PVSK (mol/l), and W represents the sample weight (g).)

• Electric charge at pH12

Deionized water was added to the polyacrylamide to a concentration of 0.5 g/l, to which an aqueous sodium hydroxide solution was added to adjust the pH level to 12. The mixture was let stand for 5 minutes, and then titrated on a particle surface electric-charge measuring equipment [Model PCD03, manufactured by Mutek] using polydiaryl dimethyl ammonium chloride (pDADMAC).

The electric charge at pH12 was obtained using the formula below:

$$\text{Electric charge (m-equivalent/g)} = V \times C / W$$

(V in the formula represents the titer of pDADMAC (ml), C represents the concentration of pDADMAC (mol/l), and W represents the sample weight (g).)

5

Table 1

Paper-strengthening agent	Electric charge at pH2 (m-equivalent/g)	Electric charge at pH12 (m-equivalent/g)
PAM-01	0.49	1.29
PAM-02	0.72	1.73
PAM-03	0.44	1.09
PAM-04	0.89	0.99
PAM-05	1.33	1.07
PAM-06	0.97	1.35
PAM-07	1.11	1.80
PAM-08	0.74	2.20
PAM-09	2.17	2.39
PAM-10	1.07	2.01
PAM-11	-	2.14

10 <Calculation of the Relative Bonding Area of a Paper Containing Polyacrylamide or Starch>

The relative bonding area of each polyacrylamide or starch was calculated as follows (using Formula 1) (reference: Philip Luner et al., TAPPI, 44 (6), 409 (1961)).

The results are shown in Table2.

$$\text{Relative bonding area} = S_0 - S_x / S_0 \text{ (Formula 1)}$$

15 (S_0 in the formula represents the specific scattering coefficient of the nonbonding sheet prepared from unbeaten pulp, and S_x represents the specific scattering coefficient of the sample.)

○ Measurement of S_0

20 Unbeaten LBKP (CSF freeness 660 ml) was mixed with 0.9 percent of aluminum sulfate relative to the absolute dry weight of pulp and 0.1 percent of polyacrylamide relative to the absolute dry weight of pulp (or 0.3 percent relative to the absolute dry weight of pulp when starch was used), and the obtained pulp slurry was measured to isolate an amount that would produce a paper sheet with a basis weight of 70 g/m². Then, the slurry was processed on a round TAPPI papermaking machine with 150 mesh wire (area 200 cm²) to obtain a paper.

Next, the paper was dewatered on a press under 1.25 kgf/cm² for 5 minutes, and then

dried by a cylinder dryer at 110°C for 60 seconds to produce a vat paper. Different vat papers were obtained by changing the press condition to 1.25 kgf/cm² for 5 minutes followed by 4.18 kgf/cm² for 2 minutes; 4.18 kgf/cm² for 5 minutes followed by 4.18 kgf/cm² for 2 minutes; and 20.0 kgf/cm² for 5 minutes followed by 20.0 kgf/cm² for 2 minutes, respectively.

5 The obtained vat papers were kept in an ambience of 23°C and 50 percent humidity for 1 day to adjust the moisture content, after which their specific scattering coefficient and breaking length were measured.

 An approximating curve was drawn by plotting the measured specific scattering coefficients and breaking lengths on a graph, and the specific scattering coefficient corresponding
10 to zero breaking length was obtained via extrapolation as S_0 .

○ Measurement of S_x

 Beaten LBKP (CSF freeness 435 ml) was mixed with 0.9 percent of aluminum sulfate relative to the absolute dry weight of pulp and 0.1 percent of polyacrylamide relative to the absolute dry weight of pulp (or 0.3 percent relative to the absolute dry weight of pulp when starch
15 was used), and the obtained pulp slurry was measured to isolate an amount that would produce a paper sheet with a basis weight of 70 g/m². Then, the slurry was processed on a round TAPPI papermaking machine with 150 mesh wire (area 200 cm²) to obtain a paper.

 Next, the paper was dewatered on a press under 4.18 kgf/cm² for 5 minutes followed by 4.18 kgf/cm² for 2 minutes, and then dried by a cylinder dryer at 110°C for 60 seconds to produce
20 a vat paper.

 The obtained vat paper was kept in an ambience of 23°C and 50 percent humidity for 1 day to adjust the moisture content, after which its specific scattering coefficient was measured as S_x .

Table 2

Paper-strengthening agent	Relative bonding area	Relative bonding area to blank
PAM-01	0.189	1.07
PAM-02	0.191	1.09
PAM-03	0.183	1.04
PAM-04	0.185	1.05
PAM-05	0.183	1.04
PAM-06	0.190	1.08
PAM-07	0.198	1.13
PAM-08	0.221	1.26
PAM-09	0.219	1.24
PAM-10	0.228	1.30
PAM-11	0.231	1.31
Starch-01	0.255	1.45
Starch-02	0.271	1.54
None	0.176	-

5 [Examples 1 through 7, Comparative Examples 1 through 4]

LBKP (CSF freeness 385 ml) was mixed with 0.9 percent of aluminum sulfate relative to the absolute dry weight of pulp, 0.3 percent of each polyacrylamide shown in Table 3 relative to the absolute dry weight of pulp, and a filler consisting of 10 weight percent of Tixolex 17 (manufactured by Rhodia) relative to the weight of paper.

10 The obtained pulp slurry was measured to isolate an amount that would produce a paper sheet with a basis weight of 60 g/m², and the slurry was processed on a round TAPPI papermaking machine with 150 mesh wire (area 200 cm²) to obtain a paper. Next, the paper was dewatered on a press under 4.18 kgf/cm² for 5 minutes followed by 4.18 kgf/cm² for 2 minutes, and then dried in stretched state at 50°C for 1 hour to produce a vat paper.

15 [Comparative Examples 5 and 6]

LBKP (CSF freeness 385 ml) was mixed with 0.9 percent of aluminum sulfate relative to the absolute dry weight of pulp, 1.0 percent of each starch shown in Table 3 relative to the absolute dry weight of pulp, and a filler consisting of 10 weight percent of Tixolex 17 (manufactured by Rhodia) relative to the weight of paper.

20 The obtained pulp slurry was measured to isolate an amount that would produce a paper sheet with a basis weight of 60 g/m², and the slurry was processed on a round TAPPI

papermaking machine with 150 mesh wire (area 200 cm²) to obtain a paper. Next, the paper was dewatered on a press under 4.18 kgf/cm² for 5 minutes followed by 4.18 kgf/cm² for 2 minutes, and then dried in stretched state at 50°C for 1 hour to produce a vat paper.

[Comparative Example 7]

- 5 A vat paper was produced in the same manner as described in Example 1, except that polyacrylamide was not added.

10 The vat papers obtained in Examples 1 through 7 and Comparative Examples 1 through 7 were kept in an ambience of 23°C and 50 percent humidity for 1 day to adjust the moisture content, after which their density, breaking length, brightness and opacity were measured using the methods described below.

The results are shown in Table 3.

- Density: In accordance with JIS P8118.
- Breaking length: In accordance with JIS P8113.
- Hunter brightness: In accordance with JIS P8123
- 15 ○ Hunter opacity: In accordance with JIS P8138

Table 3

	Paper-strength ening agent	Density (g/cm ³)	Breaking length (km)	Hunter brightness (%)	Hunter opacity (%)
Example 1	PAM-01	0.522	3.32	84.6	85.4
Example 2	PAM-02	0.522	3.31	84.5	85.5
Example 3	PAM-03	0.520	3.32	84.4	85.5
Example 4	PAM-04	0.521	3.25	84.5	85.4
Example 5	PAM-05	0.522	3.28	84.3	85.6
Example 6	PAM-06	0.523	3.20	84.4	85.4
Example 7	PAM-07	0.523	3.25	84.4	85.3
Comparative example 1	PAM-08	0.530	3.10	84.0	84.8
Comparative example 2	PAM-09	0.533	3.13	84.0	84.9
Comparative example 3	PAM-10	0.531	3.12	83.9	84.8
Comparative example 4	PAM-11	0.530	3.16	84.0	84.9
Comparative example 5	Starch-01	0.529	3.19	84.1	84.3
Comparative example 6	Starch-02	0.541	3.16	83.8	83.9
Comparative example 7	None	0.522	2.90	84.8	84.6

20

[Examples 8 through 14, Comparative Examples 8 through 11]

LBKP (CSF freeness 435 ml) was mixed with 0.9 percent of aluminum sulfate relative to the absolute dry weight of pulp, a sizing agent consisting of 0.2 percent of alkylketene dimer relative to the absolute dry weight of pulp, 0.1 percent of each polyacrylamide shown in Table 4 relative to the absolute dry weight of pulp, a filler consisting of 30 weight percent of calcium carbonate relative to the weight of paper, and a bulk-increasing agent consisting of 0.6 percent of KB-110 (manufactured by Kao) relative to the absolute dry weight of pulp.

The obtained pulp slurry was measured to isolate an amount that would produce a paper sheet with a basis weight of 80 g/m², and the slurry was processed on a round TAPPI papermaking machine with 150 mesh wire (area 200 cm²) to obtain a paper. Next, the paper was dewatered on a press under 4.18 kgf/cm² for 5 minutes followed by 4.18 kgf/cm² for 2 minutes, and then dried by a cylinder dryer at 110°C for 60 seconds to produce a vat paper.

[Comparative Examples 12 and 13]

LBKP (CSF freeness 435 ml) was mixed with 0.9 percent of aluminum sulfate relative to the absolute dry weight of pulp, a sizing agent consisting of 0.2 percent of alkylketene dimer relative to the absolute dry weight of pulp, 0.3 percent of each starch shown in Table 4 relative to the absolute dry weight of pulp, a filler consisting of 30 weight percent of calcium carbonate relative to the weight of paper, and a bulk-increasing agent consisting of 0.6 percent of KB-110 (manufactured by Kao) relative to the absolute dry weight of pulp.

The obtained pulp slurry was measured to isolate an amount that would produce a paper sheet with a basis weight of 80 g/m², and the slurry was processed on a round TAPPI papermaking machine with 150 mesh wire (area 200 cm²) to obtain a paper. Next, the paper was dewatered on a press under 4.18 kgf/cm² for 5 minutes followed by 4.18 kgf/cm² for 2 minutes, and then dried by a cylinder dryer at 110°C for 60 seconds to produce a vat paper.

[Comparative Example 14]

A vat paper was produced in the same manner as described in Example 8, except that polyacrylamide was not added.

The vat papers obtained in Examples 8 through 14 and Comparative Examples 8 through 14 were kept in an ambience of 23°C and 50 percent humidity for 1 day to adjust the moisture content, after which their density, breaking length, brightness and opacity were measured using the methods described earlier.

The results are shown in Table 4.

Table 4

	Paper-strength ening agent	Density (g/cm ³)	Breaking length (km)	Hunter brightness (%)	Hunter opacity (%)
Example 8	PAM-01	0.552	1.20	94.3	96.0
Example 9	PAM-02	0.553	1.19	89.6	95.8
Example 10	PAM-03	0.548	1.21	88.9	96.3
Example 11	PAM-04	0.554	1.18	89.5	96.0
Example 12	PAM-05	0.552	1.17	89.6	95.9
Example 13	PAM-06	0.553	1.07	95.0	95.8
Example 14	PAM-07	0.554	1.07	94.9	95.9
Comparative example 8	PAM-08	0.575	1.24	95.1	94.2
Comparative example 9	PAM-09	0.565	1.25	95.0	94.9
Comparative example 10	PAM-10	0.570	1.20	95.1	95.0
Comparative example 11	PAM-11	0.571	1.18	95.2	95.1
Comparative example 12	Starch-01	0.568	1.19	89.8	93.8
Comparative example 13	Starch-02	0.572	1.18	90.2	93.4
Comparative example 14	None	0.551	1.02	95.1	95.2

5

[Examples 15 through 21, Comparative Examples 15 through 18]

LBKP (CSF freeness 385 ml) was mixed with 0.9 percent of aluminum sulfate relative to the absolute dry weight of pulp, 0.3 percent of each polyacrylamide shown in Table 5 relative to the absolute dry weight of pulp, and a bulk-increasing agent consisting of 1.0 percent of KB-08W (manufactured by Kao) relative to the absolute dry weight of pulp.

The obtained pulp slurry was measured to isolate an amount that would produce a paper sheet with a basis weight of 60 g/m², and the slurry was processed on a round TAPPI papermaking machine with 150 mesh wire (area 200 cm²) to obtain a paper. Next, the paper was dewatered on a press under 4.18 kgf/cm² for 5 minutes followed by 4.18 kgf/cm² for 2 minutes, and then dried by a cylinder dryer at 110°C for 60 seconds to produce a vat paper.

[Comparative Examples 19 and 20]

LBKP (CSF freeness 385 ml) was mixed with 0.9 percent of aluminum sulfate relative to the absolute dry weight of pulp, 1.0 percent of each starch shown in Table 5 relative to the absolute dry weight of pulp, and a bulk-increasing agent consisting of 1.0 percent of KB-08W (manufactured by Kao) relative to the absolute dry weight of pulp.

The obtained pulp slurry was measured to isolate an amount that would produce a paper sheet with a basis weight of 60 g/m², and the slurry was processed on a round TAPPI

papermaking machine with 150 mesh wire (area 200 cm²) to obtain a paper. Next, the paper was dewatered on a press under 4.18 kgf/cm² for 5 minutes followed by 4.18 kgf/cm² for 2 minutes, and then dried by a cylinder dryer at 110°C for 60 seconds to produce a vat paper.

[Comparative Example 21]

5 A vat paper was produced in the same manner as described in Example 15, except that polyacrylamide was not added.

The vat papers obtained in Examples 15 through 21 and Comparative Examples 15 through 21 were kept in an ambience of 23°C and 50 percent humidity for 1 day to adjust the moisture content, after which their density, breaking length, brightness and opacity were
10 measured using the methods described earlier.

The results are shown in Table 5.

Table 5

	Paper-strengthening agent	Density (g/cm ³)	Breaking length (km)	Hunter brightness (%)	Hunter opacity (%)
Example 15	PAM-01	0.509	3.01	85.9	85.7
Example 16	PAM-02	0.510	2.98	85.8	85.5
Example 17	PAM-03	0.507	3.02	85.8	85.7
Example 18	PAM-04	0.510	3.00	85.7	85.6
Example 19	PAM-05	0.510	2.99	85.7	85.5
Example 20	PAM-06	0.521	2.86	85.2	85.3
Example 21	PAM-07	0.518	2.87	85.4	85.4
Comparative example 15	PAM-08	0.530	2.68	84.7	84.8
Comparative example 16	PAM-09	0.538	2.70	85.0	84.9
Comparative example 17	PAM-10	0.531	2.71	84.8	83.8
Comparative example 18	PAM-11	0.545	2.62	84.9	84.9
Comparative example 19	Starch-01	0.547	2.66	84.9	83.4
Comparative example 20	Starch-02	0.547	2.65	83.0	83.0
Comparative example 21	None	0.509	1.62	86.4	85.7

[Examples 22 through 28, Comparative Examples 22 through 25]

Softwood pulp was soaked in a 15 percent aqueous sodium hydroxide solution at 20°C for 30 minutes, and then an aqueous sulfuric acid sodium was added to neutralize the pH level.
20 Then, the mixture solution was blended with dimethylol dihydroxyethylene urea and stirred at 70°C for 2 hours to cause chemical reaction. Ten parts by weight of the obtained bridged pulp

(CSF freeness 420 ml) and 90 parts by weight of LBKP (CSF freeness 435 ml) were mixed, and the obtained pulp mixture was further blended with 0.9 percent of aluminum sulfate relative to the absolute dry weight of pulp and 0.3 percent of each polyacrylamide shown in Table 6 relative to the absolute dry weight of pulp.

5 The obtained pulp slurry was measured to isolate an amount that would produce a paper sheet with a basis weight of 60 g/m², and the slurry was processed on a round TAPPI papermaking machine with 150 mesh wire (area 200 cm²) to obtain a paper. Next, the paper was dewatered on a press under 4.18 kgf/cm² for 5 minutes followed by 4.18 kgf/cm² for 2 minutes, and then dried in stretched state at 50°C for 1 hour to produce a vat paper.

10 [Comparative Examples 26 and 27]

 Softwood pulp was soaked in a 15 percent aqueous sodium hydroxide solution at 20°C for 30 minutes, and then an aqueous sulfuric acid sodium was added to neutralize the pH level. Then, the mixture solution was blended with dimethylol dihydroxyethylene urea and stirred at 70°C for 2 hours to cause chemical reaction.

15 Ten parts by weight of the obtained bridged pulp (CSF freeness 420 ml) and 90 parts by weight of LBKP (CSF freeness 435 ml) were mixed, and the obtained pulp mixture was further blended with 0.9 percent of aluminum sulfate relative to the absolute dry weight of pulp and 1.0 percent of each starch shown in Table 6 relative to the absolute dry weight of pulp.

20 The obtained pulp slurry was measured to isolate an amount that would produce a paper sheet with a basis weight of 60 g/m², and the slurry was processed on a round TAPPI papermaking machine with 150 mesh wire (area 200 cm²) to obtain a paper. Next, the paper was dewatered on a press under 4.18 kgf/cm² for 5 minutes followed by 4.18 kgf/cm² for 2 minutes, and then dried in stretched state at 50°C for 1 hour to produce a vat paper.

 [Comparative Example 28]

25 A vat paper was produced in the same manner as described in Example 22, except that polyacrylamide was not added.

 The vat papers obtained in Examples 22 through 28 and Comparative Examples 22 through 28 were kept in an ambience of 23°C and 50 percent humidity for 1 day to adjust the moisture content, after which their density, breaking length, brightness and opacity were
30 measured using the methods described earlier.

 The results are shown in Table 6.

Table 6

	Paper-strengthening agent	Density (g/cm ³)	Breaking length (km)	Hunter brightness (%)	Hunter opacity (%)
Example 22	PAM-01	0.549	4.10	84.9	86.0
Example 23	PAM-02	0.552	4.09	84.8	85.9
Example 24	PAM-03	0.550	4.10	84.8	85.9
Example 25	PAM-04	0.552	4.08	84.9	86.0
Example 26	PAM-05	0.553	4.05	84.9	85.8
Example 27	PAM-06	0.551	4.07	84.7	85.9
Example 28	PAM-07	0.551	4.05	84.8	85.8
Comparative example 22	PAM-08	0.555	3.97	84.6	85.7
Comparative example 23	PAM-09	0.560	3.98	84.7	85.2
Comparative example 24	PAM-10	0.561	3.95	84.5	85.0
Comparative example 25	PAM-11	0.559	3.84	84.2	85.1
Comparative example 26	Starch-01	0.570	3.85	84.4	84.7
Comparative example 27	Starch-02	0.565	3.91	84.1	84.6
Comparative example 28	None	0.551	3.57	84.8	84.9

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Industrial Field of Application

As shown in Tables 3 through 6, the papers obtained in the examples that used polyacrylamides having an electric charge of 2.0 m-equivalent/g or less at pH2 and also 2.0 m-equivalent/g or less at pH12 exhibited better breaking length, higher opacity and brightness, and good optical characteristics, without showing any increase in density, compared with the papers obtained in the comparative examples that used polyacrylamides of higher electric charges or starches.

The results have also found that compared with a blank paper not containing any paper-strengthening agents (Blank), the polyacrylamides causing a smaller increase in relative bonding area (PAM-01 through PAM-07) achieve the effect intended by the present invention more prominently than the polyacrylamides causing a larger increase in relative bonding area (PAM-08 through PAM-011) or starches (Starch-01 and Starch-02).